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CHEMICAL ORDNANCE TEST EVALUATION

Prepared for:

**U.S. ARMY CHEMICAL RESEARCH AND
DEVELOPMENT LABORATORIES, FIELD
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EDGEWOOD, MARYLAND**

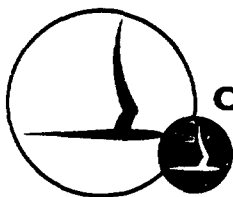
QUARTERLY PROGRESS REPORT NO. 1

By: R.F. Schneeberger

Contract No. DA 18-108-AMC-229(A)

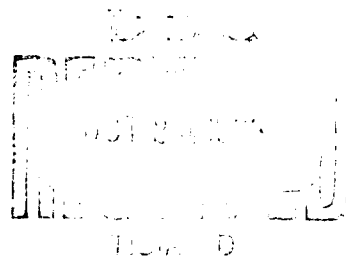
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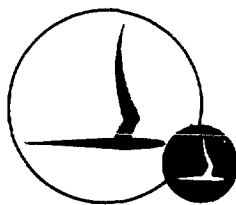
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CORNELL AERONAUTICAL LABORATORY, INC.
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I SUMMARY

This report presents a review of the studies undertaken for Project COTE, Contract DA-18-108-AMC-229(A), an investigation that is concerned with the evolution of hemical agent ordnance testing. The results obtained thus far have been primarily in the specific areas of meteorology, data analysis and chemical processing as presently performed in the Field Evaluation Division (FED) of CRDL. A test has been proposed to assist in the evolution of test accuracy and precision. It is planned that in the following period, 1) the results of this test be analyzed, 2) the meteorology study continue and the diffusion model presented be analyzed further, 3) data analysis study be continued in order to define further areas of improvement with emphasis on automation, 4) the sampling equipment and chemical processing be further analyzed to determine accuracy and precision and 5) that studies in the area of test design, process control, phase testing and the like now receiving emphasis be completed.

II INTRODUCTION

On July 5, 1963, Cornell Aeronautical Laboratory under the sponsorship of the Chemical Research and Development Laboratory, Field Evaluation Division (FED), initiated effort on Contract DA-18-108-AMC-229(A). This contract is concerned with the evaluation of the test methods and techniques presently employed by FED in the testing of chemical agent munitions. The project has been given the code name "COTE" as the abbreviated form of Chemical Ordnance Test Evaluation. This report presents a review of the effort carried out during the first quarter.

The main objectives of this project are the following:

1. To obtain estimates for the accuracy and variance of test results
2. To investigate the lengthy time factors associated with testing
3. To submit recommendations for improving the accuracy of test results or to propose areas for additional detailed investigation
4. To submit recommendations for decreasing the test time requirements
5. To develop new test concepts or propose equipment design areas which may lead to improvements in 1 and 2

During this report period primary emphasis has been placed on the assimilation of information concerning the structure, responsibilities, operation, facilities, instrumentation and techniques of FED and in the initiation of studies in the various phases of chemical ordnance testing. At present the project is staffed by six researchers together with supporting personnel working principally in the fields of meteorology, instrumentation, chemistry, and data analysis. In the following sections, the work performed in each area is discussed in detail.

III TEST DESIGN

As stated in the Introduction, the initial program effort was placed on the detailing of operations, procedures, and equipment that were employed in a field test on the main grid for the purpose of determining the accuracy and variance or precision of the test results. In Sections IV through VII, the various steps are considered. From a review of those sections, it can readily be seen that the number of investigations required to develop answers for this method of attack has become quite large and that the time required to perform all these investigations would be beyond the limits of this contract. Further, it can be argued that while the step-by-step analysis would lead to a complete description of the FED test operation, in a short program in which the main objective is the evaluation of the overall operation, and in which there is little or no a priori knowledge of the true problem areas, considerable time can be spent in the study of areas which do not contribute significantly to the overall problem. Therefore, a different method of attack was clearly indicated.

In the interpretation of the results of a given test or in the comparison of results of different tests conducted on the same munition and under similar meteorological conditions, it is required that the accuracy and precision of the data be known. The data analyst must have some measure of the variability of the individual data points if he is to compare two tests. Secondly, in order to measure the munition efficiency, he must have some knowledge of the accuracy of each data point. Here, the statistical definitions of variance and accuracy are employed. The variance or precision is the spread in data obtained in samplers which are subjected to identical concentrations of agent. The accuracy is a measure of the degree to which the average of the data obtained for the n samplers above deviates from the true value that would be obtained from perfect sampling and chemical analysis - that is, a perfect measurement.

A more direct method of determining these statistical functions is one in which tests are performed on the overall system. This method is presently being developed, and the first of a series of tests has been proposed to FED.

The first test, termed "Calibration Test" is included for the purpose of producing estimates of the variance associated with the test methods. In addition, calibrations will be employed which will produce estimates of the variance in chemical analysis alone and of the accuracy of that analysis.

In the "Calibration Test" three samplers of the same type will be placed at each grid instrumentation point and will function at the same flow rates (within the precision of the associated orifices) for the same length of time. The samples will be collected and processed as three individual tests, and the results will be analyzed to determine the overall variance in area dosage. In addition, some points will contain six samplers, three of which will be used in the analysis above. The remaining three will be processed at the same time to determine the variance in sampling, and, by comparison with the other three samplers, to determine the influence of time on the variance.

The sampling operation can be conveniently divided into two distinct phases, namely sampling and chemical analysis. From a systems analysis point of view, it would be desirable to determine which of these areas presented the greatest contribution to the overall variance because both phases are complex but may not need refinement in the event that the overall variance is excessive. To obtain this separation, a set of prepared known standards will be included in test racks containing the field samples and will be treated as field samples in the chemical analysis phase. The variance in these standards as measured in chemical analysis will then be used to obtain an estimate of the chemical processing variance. Also, the deviation of the analysis results from the true values for the standards will serve as a measure of the accuracy of the process.

It is expected that the "Calibration Test" will present the following information:

1. The variance in samplers positioned at the same point (approximately) on the field grid
2. An estimate of the possible spread in area dosage results

3. The existence of unexpected events such as the measurement of large dosages in areas significantly removed from the major cloud areas should such an event occur
4. A measure of chemical analysis accuracy
5. A measure of chemical analysis variance

Other tests which will likely be of smaller scale than the above will be developed. One important area for investigation is the accuracy of the sampler as employed in the field. It is difficult to conceive a field test which will allow such a measurement, however, and it is highly likely therefore that such a test will be performed in the wind tunnel. Following successful tests of these types, others may be formulated to determine the weak areas if such are required.

The analysis of results from the "Calibration Test" data will be an area of considerable effort during the next report period. In addition, the test phase of munitions design will receive considerable emphasis from the point of view of test design. Work presently in progress includes a) studies of test data requirements, b) study of local control of sample data and c) study of system controls which will provide continuing assessment of process quality.

IV METEOROLOGY

The meteorological studies which are being conducted on the project are directed toward an evaluation of the meteorological instrumentation at the field test sites, the application of meteorological data to the analysis of test results and the determination of methods by which tests can be carried out to yield more accurate and useful results. Problems considered to be of importance are concerned with 1) the accuracy and representativeness of meteorological measurements made in the field, 2) the methods by which meteorological data are used in the analysis of test results, 3) the variability in test results to be expected due to natural variability of wind and turbulence, and 4) ways of comparing test results obtained under different meteorological conditions. The following sections describe the progress made to date in each of these areas. Emphasis thus far has been placed on 2 and 3. Items 1 and 4 will receive a major part of the attention during the remaining contract period.

a) Present Meteorological System

The basic meteorological equipment at the Carroll Island test site consists of cup anemometers and vanes for the measurement of wind speed and direction, and shielded, un aspirated thermocouples for the measurement of temperature and vertical temperature gradient. Other instruments are occasionally used or tested but are not available for routine use. Anemometer positions are provided at four points on a 30-yard circle (Figure 1). At two of these, wind profiles may be obtained from anemometers at heights of 0.5, 1, 2, 4, and 8 meters. At the other two positions, wind speed is observed only at the 2-meter height. Wind direction is observed at a 2-meter height only, at all four field positions. Separated from the wind-observing sites, the position for measuring temperature gradient is located near the 40-yard arc on the west side of the grid. All data are remotely recorded in a hut beyond the test grid.

Carroll Island does not provide an ideal location for micrometeorological studies. The nature of the surface is variable, consisting partly of grass cover and partly of bare ground, with stands of trees beyond the grid at varying distances in different directions. The uneven ground cover and the obstructions

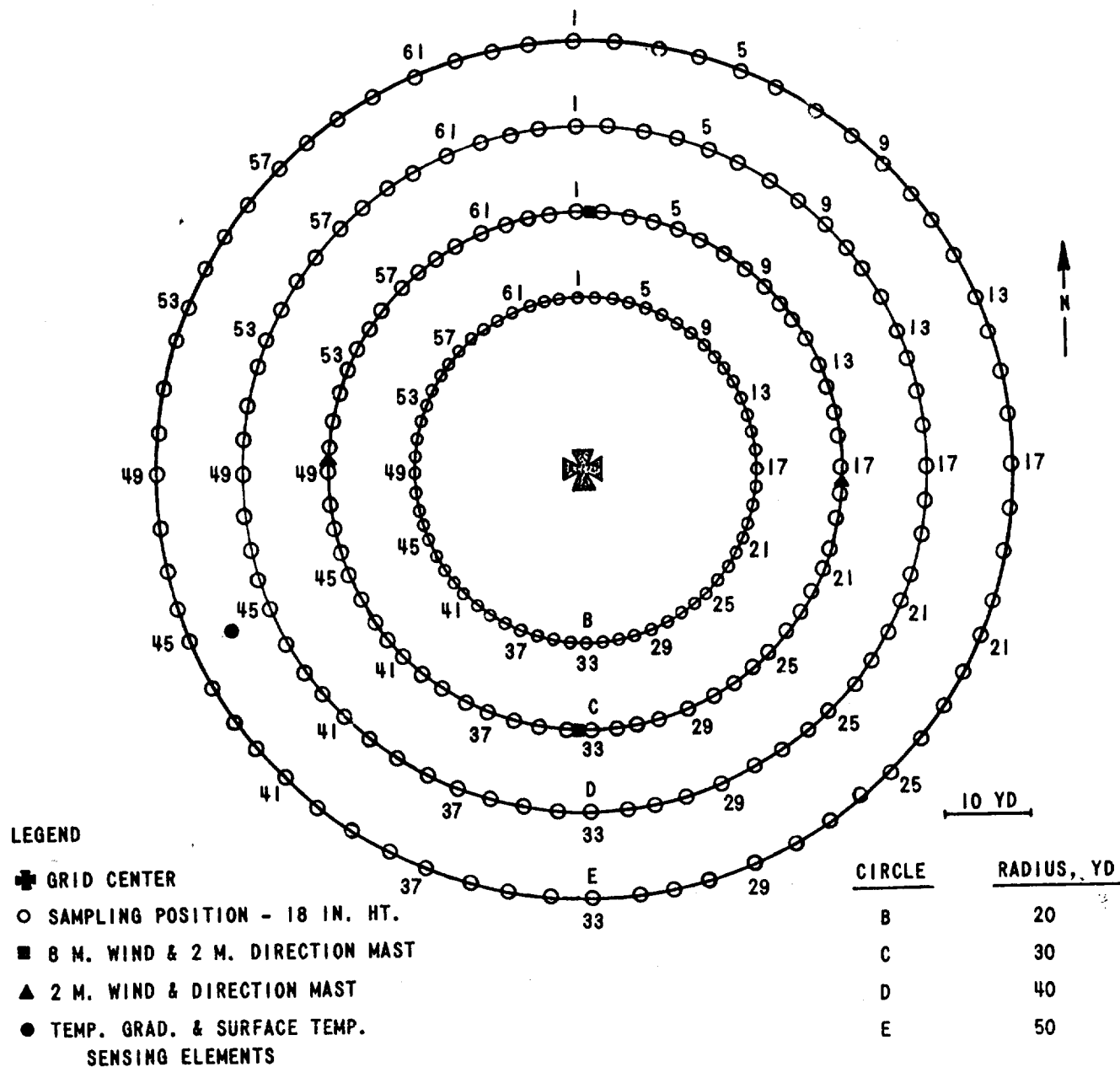


Figure 1 CARROLL ISLAND TEST FACILITY (CRDL)

to flow due to grid instrumentation are, of course, nearly unavoidable. These features do not necessarily restrict the usefulness of measurements; however, in this situation one cannot expect to find smooth, fully developed wind and temperature profiles of the kind observed at carefully chosen, highly uniform meteorological field sites. Similarly, the unequal amounts of unobstructed terrain in different directions from the grid impose little restriction on the usefulness of the site for munition testing. However, the nature of the turbulence (and therefore the diffusion) will differ according to wind direction; therefore, results obtained on the basis of different wind directions are not directly comparable. It is estimated that the distance from grid center to trees varies between 200 and 500 yards, depending on direction. Even the greatest of these distances is not sufficient to insure a fully developed wind profile and turbulence structure up to the highest levels at which wind is measured (8 m).

Of greater importance is the actual exposure of the anemometers. Because of the dense array of sampling equipment and supports on the vertical grid, care should be taken to mount anemometers in a position where there is minimum interference to the air flow. It has been noticed that at the grid, several anemometers were in a position rather close to large supporting pipes. Poor anemometer exposure will give incorrect measures of the mean wind, thereby possibly contributing to error in test results.

The accuracy and sensitivity of the existing wind and temperature instruments have not yet been satisfactorily determined. Estimates will be made in the near future when the data resulting from comparison runs with better instrumentation will be available. Inspection of the present field instruments and discussion with CRDL personnel indicated that appreciable errors may exist under some circumstances. Wind vanes showed poor response in light winds. Brief inspection of the first anemometer comparison runs has shown that the present anemometers are relatively insensitive and have a slow response. The installation of better, more sensitive wind equipment that is planned will increase the reliability of wind data.

Present temperature-gradient measurements also seem to be lacking in desired accuracy. FED personnel noted that scatter was unreasonably large during some observation periods with the present shielded thermocouple system. The first run has shown that scatter does not exist with aspirated couples.

The differences indicate that radiation errors resulting from inadequate shielding occur during daytime with the present thermocouples. There is also evidence of a small systematic difference occurring at all times between the two sets of instruments.

Field instruments at Carrolls Island are not regularly serviced or calibrated because of the lack of time and manpower, and facility shortages. Owing to the sensitivity required of micrometeorological instruments and their long exposure to extremes of weather, regular checking is a necessity. Some provision should be made for regular checks in the field by comparison with standard instruments. Anemometers should occasionally be serviced and re-calibrated in a wind tunnel.

b) Use of Meteorological Data in Test Analysis

One of the principle uses of meteorological data is the determination of conditions suitable for testing. Specific conditions are usually called for in the test plan, and safety considerations impose other restrictions. Extremely accurate data are usually not needed for making test decisions, however, and our concern is more with the actual use of data in the analysis of test results.

In only one common type of analysis does a meteorological parameter appear as a basic input — the determination of transport through the vertical grid. For other analyses, wind or temperature data may be consulted to help in interpretation, but they are not used directly. In the vertical grid analysis, the total amount of agent which passed through the grid is calculated from the measured dosages. The total agent R passing through an area A on the vertical grid in sampling time T may be written

$$R = KA \int_T VC dt \quad (1)$$

where K is a constant inserted to correct for a circular arc, V is the wind speed, C is the instantaneous concentration at the sampler (assumed to represent the area), and t is time.

We can re-write the integral

$$\int_T VC dt = T \overline{VC}$$

where the bar ($\overline{\quad}$) denotes the average value of the product VC over time T.

Thus:

$$R = KAT \overline{VC} \quad (2)$$

We use the common technique of dividing the variables V and C into their mean values plus deviations from the mean, that is:

$$V(t) = \overline{V} + V'(t), \quad C(t) = \overline{C} + C'(t)$$

The primed symbols denote deviations from the mean. Then we have

$$\overline{VC} = \overline{V} \overline{C} + \overline{V' C'}$$

The term $\overline{V' C'}$ is the average value of the product of the deviations from average of V and C. It is proportional to the correlation between V' and C'. Now, substituting into the equation for R, we obtain

$$R = KAT (\overline{V} \overline{C} + \overline{V' C'}) \quad (3)$$

The concentration is never measured, only the total dosage $D = \overline{C} T$.

Rewriting eq. (3) in terms of D yields

$$R = KA \overline{V} D + KAT \overline{V' C'} \quad (4)$$

In analyzing vertical grid tests, the first term of equation (4) is used to calculate total agent R. The mean wind \overline{V} is estimated for the sampling period from the wind speed traces. The second term is neglected.

As discussed in section VII of this report, the FED method of estimating \overline{V} gives good results. The accuracy of the recorded V is not known but indications are that small errors in V do not seriously effect the final value of R as long as the errors are not systematic through all heights. But the neglect of the second term in (4) could lead to larger errors. Since the instantaneous concentration is not measured, there is no convenient way to estimate the likely

error, but it is easy to see how such an error could exist. Consider a case in which the cloud passes through the grid in a time small compared to the sampling interval. If the wind speed is at a peak or lull during cloud passage, the actual wind speed then may be much different from the mean wind speed \bar{V} . Such an occurrence would lead to strong correlation between V' and C' , thus a large value of the second term in (4). During unstable (daytime) conditions, gustiness is to be expected and short term wind speeds 20 percent higher or lower than the mean are common.

In actual practice, the dosages for a single level are often lumped together for analysis. This procedure does not materially change the probability of error, for appreciable wind fluctuations will effect all samplers in the same way, and the errors are additive. Thus, a possibility for error exists when computing agent flux through the vertical grid with mean wind speeds. Attempts will be made to define more accurately the probable limits of this error in future work. The only possibility for reducing the error, aside from the use of much shorter sampling periods, is to define the actual time of cloud passage and to use wind speeds appropriate to that time. The tracer concept to be described in Section IX could also be useful in solving this problem.

c) Additional Uses of Present Data

It would be of obvious advantage to determine improvements in testing and analysis that could be realized by means of currently available meteorological data. It is assumed, of course, that the present types of information can be obtained with acceptable accuracy. Consequently, some effort is being devoted to finding further uses of routine wind and temperature data in the testing program.

Two possibilities may be noted. One is to increase the reliability of vertical grid calculations by using more detailed wind information. For short sampling periods, movies of the cloud diffusion could be used to estimate the time of main cloud passage, so that wind speeds appropriate to this time could be applied. For long period sampling, the shorter period dosages could be used to divide the process into shorter time steps, in each of which the transport through the grid would be calculated by means of the corresponding short-period mean wind. Definite recommendations for such a procedure will be made if our error analysis indicates that it would significantly improve results.

A second use of current data is for study of the relations between field test results and meteorological conditions. Such studies have been made in the past at FED, but they could be revised and extended when new data of increased reliability are obtained. Such studies would be more informative if test plans were devised to include significantly different ranges of meteorological variables.

d) Natural Variability of Diffusion Patterns

The purpose of a field test is to evaluate such characteristics as area coverage and percent return from a particular chemical munition. In other parts of this report, we consider factors which can lead to errors in these test results. One other factor must be considered in evaluating the representativeness of a test result, however. That is the variability in test results that will occur due to the natural variation of wind. If it is assumed that sampling and analysis could be performed without error, the results of several tests performed with the same munition under identical conditions of mean wind and temperature would not always be the same. The essentially random fluctuations of wind on all scales will lead to a statistical variability in test results. It is obviously important to know how great this variability is. Knowledge of the variance will indicate the minimum difference between munitions which can be reliably detected, and the number of tests needed to specify results with a given level of confidence.

Nearly all diffusion models are designed to predict the average concentrations over long periods of time or for many trials. Thus, no information is given about the variability over short periods or between trials. An exception is the fluctuating plume model derived by Gifford.⁽¹⁾ We have modified this model to apply to instantaneous sources in an effort to estimate the variance in individual trials conducted under identical conditions of mean wind and temperature gradient. The model will be presented briefly here. For details the reader is referred to Gifford's original paper.

Consider a vapor cloud from an instantaneous volume source. It is assumed that the distribution of material within the cloud is Gaussian

in the y (cross wind) and z (vertical) directions. Diffusion in the x (along-wind) direction is assumed negligible. This assumption is of course unrealistic, but it will not seriously change our results. By considering the cloud as a disk with fixed but limited extent in the x direction, we can interpret instantaneous concentrations in terms of total dosage. Alternatively, we can consider the equations as applying to "downwind integrated concentration." In either case, the error in dosage due to neglect of downwind diffusion would be significant only if the cloud passed the sampling lines at a small angle. As long as the cloud moves in approximately the mean wind direction, we are justified in neglecting diffusion along the x axis.

The origin of a moving coordinate system is taken as the position the cloud center would occupy if it moved in the direction of the mean wind at the mean wind speed. We imagine that the actual position of the cloud center will at any instant be at $x = D_x = 0$, $y = D_y$, $z = D_z$ relative to the moving origin. In other words, the position of the real cloud may fluctuate about the position expected from the mean wind. The distribution of material with respect to the moving center of coordinates is now given, according to our assumptions, by

$$\frac{C}{Q} = (2\pi \overline{y^2})^{-1/2} \exp \left[-\frac{1}{2} \frac{(y - D_y)^2 + (z - D_z)^2}{\overline{y^2}} \right] \quad (5)$$

where C = downwind integrated concentration of diffusing material (mass per unit area normal to mean wind)

Q = total amount of material released

$\overline{y^2}$ = variance of material distribution about the actual cloud center

We have assumed that diffusion proceeds equally in the y and z directions, i.e. $\overline{y^2} = \overline{z^2}$. The value of $\overline{y^2}$ is of course a function of the time since release and the characteristics of the turbulence.

The next step in the derivation is to specify the probability distribution of D_y and D_z . Here, we assume that the fluctuations of cloud center position in the y and z directions are independent, that the displacements observed over many trials at a given downwind distance have a Gaussian distribution, and that the variances of actual center positions are equal for the two directions and given by $\overline{D^2}$. Again, $\overline{D^2}$ will depend on time and meteorological conditions. The joint frequency function of D_y and D_z is taken as

$$g(D_y, D_z) = (2\pi \overline{D^2})^{-1} \exp \left[-\frac{1}{2} \frac{D_y^2 + D_z^2}{\overline{D^2}} \right] \quad (6)$$

From eqs. (5) and (6) and our assumptions, it is possible to derive the mean concentration distribution over many trials, the variance of concentration among trials, and even the frequency distribution of concentration at any point. The mean concentration is

$$\frac{\bar{c}}{Q} = [2\pi(\overline{y^2} + \overline{D^2})]^{-1} \exp \left[-\frac{1}{2} \frac{y^2 + z^2}{\overline{y^2} + \overline{D^2}} \right] \quad (7)$$

The variance of concentration is

$$\begin{aligned} v &= \overline{\left(\frac{c}{Q}\right)^2} - \left(\frac{\bar{c}}{Q}\right)^2 \\ &= [2\pi]^{-2} \left\{ \frac{\exp \left[-\frac{y^2 + z^2}{2(\overline{D^2} + \overline{y^2})} \right]}{\overline{y^2}(\overline{D^2} + \overline{y^2})} - \frac{\exp \left[-\frac{y^2 + z^2}{\overline{y^2} + \overline{D^2}} \right]}{(\overline{y^2} + \overline{D^2})^2} \right\} \quad (8) \end{aligned}$$

Eq. (8) permits us to calculate the variance of point concentrations, given values of the parameters $\overline{y^2}$ and $\overline{D^2}$. Gifford has shown how these variables are related to similar parameters whose values have been estimated and reported in the literature. (Also see Pasquill⁽²⁾.)

For an example, let us take a position 30 meters downwind of a point source. Assume a mean wind of 5 m sec^{-1} . Then the cloud will reach the sampling position 6 sec after release, according to our model. The

parameter $\overline{y^2}$ can be estimated from data on the growth of smoke puffs. Values have been given by Frenkiel and Katz⁽³⁾ and by Smith and Hay.⁽⁴⁾ For neutral stability and a 5-m/sec wind, the value $\overline{y^2} = 7.5 \times 10^3 \text{ cm}^2$ is typical for a small cloud 30 meters from the source. Data on the width of continuous plumes of smoke may be used to estimate $\overline{D^2}$, since the average cross-wind variance of concentration in a plume should equal $\overline{y^2} + \overline{D^2}$. From results by Cramer⁽⁵⁾, an estimate of $\overline{D^2} = 14 \times 10^4 \text{ cm}^2$ has been obtained. Applying these estimates in eqs. (7) and (8), we find for $x = y = z = 0$, at the expected position of cloud center:

$$\frac{\overline{C}}{Q} = 1.07 \times 10^{-6} \text{ cm}^{-2}$$

and

$$V = 1.06 \times 10^{-11} \text{ cm}^{-4}$$

$$\text{Standard Deviation} = V^{1/2} = 3.26 \times 10^{-6} \text{ cm}^{-2}$$

This example, believed to be representative of typical conditions at the field test site, indicates that the concentration of agent as observed in a particular test, can be expected to differ from the mean over many tests by a factor possibly as large as three. As mentioned earlier, the neglect of diffusion in the x direction means that we can interpret concentrations in terms of total dosage. The dosage can be shown to vary by the same fraction as the concentration in our model.

The above model is admittedly crude; no account has been taken of the effect of the ground, the possibility of different diffusion rates in different directions, or an uneven distribution of material in the original cloud. Most of these factors can be taken into consideration in a more elaborate model. The equations have not yet been satisfactorily applied to the problem of estimating variability in the total agent flux through the vertical grid or the area-dosage curves. However, certain conclusions may be drawn from these preliminary results and past experience with diffusion data:

1. For different tests of the same munition, conducted under similar meteorological conditions, the dosage at any particular point on the grid will be highly variable.
2. Area-dosage relationships will probably show considerable natural variation for some types of munition. Fluctuations in the motion of a cloud in the horizontal plane are expected to have little effect on area-dosage results, but vertical cloud movements will generally occur, and these will produce variability in area coverage at any specific level.

Further work with the "fluctuating path" model will be carried out to extend our results and attempt to provide values for the variance of area-dosage estimates.

e) Summary and Plans for Future Work

Progress during the first quarter of the contract period in the meteorological phase of our work has included:

1. Inspection of field meteorological facilities and preliminary checks on instrument characteristics
2. Analysis of present uses of meteorological data in test analysis
3. Development of a model to specify the variability of dosage under given meteorological conditions
4. Preliminary consideration of new techniques for evaluating meteorological factors in test results

During the next contract period, our efforts will be devoted to:

1. Analysis of errors and characteristics of meteorological instrumentation (using comparison data supplied by FED)
2. Continued development of a model to predict natural variance in test results

3. Outlining of requirements for instrumentation and research to improve meteorological operation
4. Specification of improved techniques and methods for relating meteorological factors to test results

V SAMPLE STUDY

In the previous section, the subject of variations in expected agent concentrations as a function of meteorological inputs was considered. The results of the suggested study are of considerable importance in data interpretation and in test planning. However, a review of the results obtained in present FED test programs shows that even under the most highly controlled conditions, as in wind tunnel tests, the variability in data is such that a high level of confidence cannot be placed in the results. The major remaining contribution to variance is the sampler employed.

In the following, a sampler type is studied and a functional equation is presented. The aim of this study was to denote the characteristics of the sampler considered to be of importance and also the parameters influencing its operation.

a) The Snoot Sampler

It is assumed that a rectangular cloud is moving at a velocity v toward the "Snoot." The cloud contains an amount of mass initially containing vapor and particles uniformly distributed. The mass is composed of agent (M_a), decomposition products (M_d), contamination material (M_c) and material inert to agent and the chemical processes following (M_i). Since M_i is considered inert to the agent and processes, and assuming the actual volume of M_i actually collected to be a very small fraction of the volume of solvent employed, M_i will be neglected.

Assuming nonturbulent flow, the filter paper ideally collects an amount of material

$$M_I = \rho M_O$$

where M_I is the ideal mass collected

M_O is the material in the cloud = $M_a + M_d + M_c$

ρ is the ratio of the sampler aperture to the cloud cross section
(area of responsibility)

Now the sampler is isokinetic at only a single wind speed for a given flow rate. At that flow rate and for any other wind speed, the stream lines at the aperture are deformed, and the amount of material collected will be in error if isokinetic sampling is assumed. Then the amount of material collected is related to that which would be ideally collected by an efficiency factor which is a function of wind speed (v) and particle size distribution (w). This factor $f(v, w)$ is considered to include the losses due to deformed stream lines, particle motion in such a field, and losses due to turbulence which may be generated inside the Snoot cavity. For isokinetic conditions $f(v, w)$ is of course unity. Thus the mass actually collected is given by

$$M_2 = M_1 f(v, w)$$

Because of imperfect alignment of the aperture and changing wind direction, the aperture may not be properly directed at the cloud. (The aperture normal may not be parallel to the wind direction.) Assuming again that an efficiency figure can be derived which is a function of the angle between the aperture normal and the wind vector $\alpha (\Theta)$, the mass collected is

$$M_3 = M_2 \alpha (\Theta).$$

Note that an assumption has been made here that the aerodynamics of the cloud in the vicinity of the Snoot are not altered by this misorientation. If the foregoing statement is not true, then $f(v, w)$ should also be a function of Θ .

Ideally, all the material M_3 , the amount impinging on the filter paper, is collected. However, there is an efficiency h associated with such filter paper, which is a function of the particle size, flow rate v_f , and possibly temperature (T) and humidity (H) which is expressed here as $h(v_f, w, T, H)$. Additionally, at the filter, the mass M_a is brought into contact with M_c , the contamination material, and part of M_a is reduced to decomposition products. This process is a function of the amount of materials of each type present, on the chemical reaction rates, and the time during which contact is allowed before being placed in solvent. Let this input be represented by the functional relation $d(\Phi_1, H, T, t_1)$ where Φ_1 represents the chemical rates.

The amount of material thus ideally collected by the filter is $M_4 = M_3 h(v_f, w, T, H) d_1(\Phi_1, H, T, t_1)$. However, the sampler is generally operated for a period of time which is long compared to that required for cloud passage. There exists for that time the possibility that some of the material collected will be evaporated into the vacuum line. Therefore, a filter retention efficiency figure should be considered. This figure, which is a function of the volume of air drawn through the sampler (flow rate times time t), the vapor pressure of the material and the air, and the air temperature, is expressed as $e(v_f t, p_m, p_a, T)$ to give $M_5 = M_4 e(v_f t, p_m, p_a, T)$.

The effect of storage time in solvent may introduce additional loss of agent represented by the factor $m(t_s, \Phi_2)$ where t_s is storage time and Φ_2 represents the chemical processes, giving:

$$M_6 = M_5 m(t_s, \Phi_2)$$

M_6 is the amount of agent presented to the chemical analysis processing. There is, of course, an accuracy associated with chemical analysis which may be represented by the efficiency factor $c(C)$ to give a measured Klett reading of

$$M_7 = M_6 c(C) = \text{Klett Reading (gross)}$$

The accuracy of the sampling process is considered to be established by the measurement of M_6 with $c(C)$ being taken as the subject of a separate analysis. When all the functional equations are combined, a comprehensive equation results:

$$M_6 = \int M_a m(t_s, \Phi_2) e(v_f t, p_m, p_a, T) h(v_f, w, T, H) d(\Phi_1, H, T, t_1) a(\Theta) f(v, w)$$

Ideally all the functionals in this expression would be unity and constant with respect to all the variables such that

$$M_6 = \int M_a$$

While such a development serves to illustrate the processes and variables involved, it is of relatively little value in obtaining actual results because of the variety of parameters and the complexity (anticipated) of the functionals involved. For example, the functions $f(v, w)$ and $a(\Theta)$ enter because the sampler must operate at an aperture flow rate equal to the wind speed prevailing, and the aperture must be directed into the wind. The problems involved are those concerning gas and particle dynamics and include the aerodynamic design of the sampler itself. However, a practical solution may be obtained by obtaining reliable estimates of the functionals for those parameters found to be of importance through an experimental approach. Such an approach is now being formulated and will be discussed in the report for the next period.

b) Data Analysis

Indications of sampler accuracy problems have been found in existing FED test data. In some tests sequential sampling and total dosage sampling are employed. If the samplers are considered to give a true representation of chemical dosage, then the sum of the sequential sampler dosages should equal the total dosage sample. In the data for field tests 1421 and 1422, it was observed that the sum of the dosages for the 0 to 15-second, 15 to 30-second, 30-second to 2-minute, 2 to 10-minute, and 10 to 30-minute sampling intervals was usually less than the 0 to 30-minute (total) dosage. The averages of the total dosage, sum of dosages, differences, and variance in difference were computed for each arc of field test 1421. These results are presented in Table 1.

An attempt was made to explain these average differences as being the result of a delay in time between the turning on of the samplers and the beginning of their operation. This delay could be the result of sampler design (in which case the delay would be uniform) or of slow drops in pressure in vacuum lines because of leaks or insufficient pump capacity. It was assumed that the time delay was the same for all samplers, but was zero for the 0 to 30-minute and 0 to 15-second intervals because those samplers were turned on early. The calculations based on average total dosage and average

TABLE 1

Arc	Average Total Dosage	Average Sum of Dosages	Average Difference	Variance	Number of Points
B	17.8	15.5	2.3	12.0	25
C	17.3	16.0	1.3	21.7	23
D	25.4	13.2	12.2	9.4	9
E	18.8	19.5	- .66	5.4	6
F	11.6	7.8	3.8	5.5	5
G	24.0	22.0	2.0	0	1
H	28.5	2.5	26.0	31.2	4
I	5.3	1.3	4.0	0	3

sums of dosages for each one gave delay times from 5.6 seconds to 66 seconds and a negative time of 2.6 seconds for arc E. Such delay times are of course unrealistic and hence other explanations must be sought.

It is planned that further investigation of FED data will be performed in the following period and additional test proposals will be presented. Some effort will likewise be spent on activities such as development of calibration techniques, the inclusion of such techniques in the FED operation, and the development of long-range tests to determine in greater detail the influence of the various parameters on the sampling accuracy and similar subjects.

VI CHEMICAL PROCESSING ANALYSIS

As indicated in the previous sections, an exhaustive study of the chemical procedures has not been undertaken. However a preliminary breakdown of the chemical calculations has been made, and fairly detailed descriptions of several of the chemical analysis procedures have been assembled.

Some reasons for this approach were:

1. To provide a coherent overall picture of the chemical part of the operation.
2. To form an idea of the inherent difficulties and possible trouble areas.
3. To suggest some simple preliminary tests which would give an estimate for the variances to be expected in key parts of the operation.

This approach will also provide a start toward a more detailed breakdown of the chemical analysis operation if the results of the calibration field test (Section III) show it to be warranted.

a) Chemical Procedure at FED

Detailed descriptions of the analytical procedures used by FED for VX and GB have been assembled. Tentative indications of some possible trouble areas have been included, based on observations at FED as well as on talks with leading chemists at FED and at CAL. The comments immediately following are generally applicable to all of the chemical processing.

Practically all analysis of field samples at FED is done by colorimetry. This is probably the most suitable of the older methods, given the large number of samples to be processed and the small concentrations involved. The method is much faster than the standard gravimetric and volumetric techniques and can detect much smaller quantities of material than either, in most cases. Furthermore, the method makes much less demand on the skill of the operator than would microanalysis techniques.

There are two principle disadvantages to colorimetric analysis:

1. The method is empirical, i. e. , a set of synthetic standards must be analyzed to provide a calibration curve. The standards should be treated identically to the samples to be analyzed, but this requirement is often difficult to carry out in practice.
2. Since colorimetry measures concentration rather than sample content, the final volume at measurement must be held constant for all samples and standards within the accuracy of the determination. This means that every addition of reagent, and every loss of solvent (e. g. , by evaporation) is a potential source of error.

The only exception to the use of colorimetry at FED is in the determination of the ratio of active agent to total phosphorus for the munition charge. This determination is accomplished by gas chromatography.

b) Breakdown of the Chemical Calculations

Two types of results are obtained from the chemical analysis, depending on the type of samplers involved. These are dosages (the integrated product of volume concentration and time) and area densities.

The dosages reported may be represented by:

$$D = S \cdot K_n \cdot \frac{v_s}{v_a} \cdot \frac{v_d}{v_{a'}} \cdot \frac{1}{F} \cdot \frac{1}{E} \quad (1)$$

where:

K_n = Net "Klett" reading = $K_g - K_b$

K_g = Gross Klett reading, the colorimeter reading obtained from the sample

K_b = Average of the field blank readings

S = "Sensitivity Factor," the slope of the standard curve determined from 5 or 6 standards and a laboratory blank run in triplicate. The curve is assumed to be a straight line since the Klett scale is logarithmic

v_a = Volume of the aliquot taken for analysis

v_s = Total volume of solvent used in the samples

$v_{a'}$ = Volume of aliquot taken for dilution from a concentrated sample

v_d = Volume to which the first aliquot is diluted

F = Flow rate of air through the samples

E = Efficiency of the sampling device

D is expressed in $\mu\text{ g minutes/m}^3$.

Area density measurements can be represented by:

$$L = S \cdot K_n \cdot \frac{v_a}{v_s} \left(\frac{v_d}{v_{a'}} \right) \cdot \frac{1}{A} \cdot \frac{1}{E} \quad (2)$$

Where A is the effective area of the sampler. The other symbols have the same meaning as in eq. (1). Area density is usually expressed in gm/m^2 .

One would expect that $\sigma(D)$, the standard deviation of dosage, could be obtained from:

$$\left(\frac{\sigma(D)}{D} \right)^2 = \sum_i \left(\frac{\sigma(x_i)}{x_i} \right)^2 \quad (3)$$

where the x_i stands for the various factors appearing in (1) or (2). These factors will now be considered:

S FED believes their analyses to be accurate within 5 percent. Assuming (a) that this refers only to the chemical processing, and (b) that the volume errors are negligible, 5 percent would presumably be just the error in S. If their estimate is correct, then

$$\frac{\sigma(S)}{S} \approx .05$$

$$\underline{K_n} (\sigma(K_n))^2 = (\sigma(K_g))^2 + (\sigma(K_b))^2$$

$\sigma(K_g)$ is the error in the actual colorimeter reading.

2 ml pipette: a similar test was made on a single pipette. It was found $\sigma(v_a)/v_a = .0025$. Deviation from the ideal volume was -0.3 percent.

Since the same devices are used to take the aliquots for dilution, the same standard deviations would apply to v_a' . It should be pointed out that a systematic error in v_a need not introduce an error into the final result, provided that the same systematic error was made during analysis of the standard samples which were used to obtain S. On the other hand, a systematic error in v_a' will directly affect the results of analysis if the same calibration curve is used for diluted and undiluted samples.

For hexylene glycol samples, aliquots for analysis (v_a) are taken by pouring an excess over 5 ml into racked test tubes and then drawing these down to a standard height with a vacuum probe. The precision of this operation depends on the constancy of the test tube diameters and of the racking heights.

A test of the above procedure was made by weighting the individual aliquots delivered to one complete rack of test tubes (40 samples). A value of .026 was found for $\sigma(v_a)$. However, the mean volume deviated from the ideal volume by -6.3 percent. It is not possible without further tests to discriminate between three possibilities:

1. The particular rack may have been defective
2. The vacuum suction device may have been out of adjustment, in which case the comment above about systematic errors in v_a applies
3. The 6.3 percent figure may be representative of a large standard deviation among racks

FED estimates $\sigma(K_g) \approx \pm 2$ "Klett units." $\sigma(K_n)/K_n$ could be very large for the low dosages, for which $K_n \rightarrow 0$. However, at the larger dosages for which $K_n > 100$, $\sigma(K_n)/K_n$ is probably negligible. These latter measurements contribute most to the estimate of total recovery. CAL presently considers a constant percentage error of about 1 percent to be more realistic, since the Klett scale is essentially logarithmic.

v_a'/v_d

The factor (v_a'/v_d) in eqs. (1) and (2) applies only to concentrated samples for which dilutions must be made. Otherwise $(v_a'/v_d) = 1$ identically.

v_s, v_d

These volumes are delivered by Filamatic or Volustat units for which the manufacturers claim a tolerance of 1 percent that is $\frac{\sigma(v)}{v} \approx .01$.

v_a, v_a'

For thin liquids (isopropanol or N_aOH solution) vacuum pipettes are used. Since these are not standard items, it was considered desirable to run some accuracy tests.

5 ml pipette: 10 samples of isopropanol were taken with a single pipette by the same operator, and weighed. A value was found for $\sigma(v_a)/v_a = .002$. A deviation of the mean volume from the ideal volume of -3.5 percent was found, based on the density quoted in the Chemical Rubber Company Handbook. This test, of course, gives no information about possible variations between different pipettes or between different operators.

It would be desirable to clear up this point by testing a number (at least 10) of racks randomly chosen from among those regularly in use. It would not be necessary to weight each sample, but would be sufficient to obtain the total weight of all samples delivered to a given rack. Since about 190 gm of solvent would be weighted per rack, 0.1-gm precision would be adequate.

Aliquots of hexylene glycol for dilution are taken with a syringe (v_a'). Since manufacturer's data was not immediately available, a test was on a single syringe similar to the tests of the vacuum pipettes. It was found that $(v_a)/v_a' = .002$. Deviation of the mean from the ideal volume was -1.2 percent.

F Critical orifices for flow-type samples are checked in the laboratory at FED. Bubbler orifices are retained within the range 0.9 - 1.1 ℓ/min indicating $(F)/F' = 0.1$. This does not take account of effects due to the complete bubbler train or due to variations in vacuum at the field.

The snoot-orifices are held to much closer tolerances. A check of 22 snoot samplers and orifices assembled as for field test yielded a value of $\sigma (F)/F = .009$. The average flow rate in the laboratory was 6.3 ℓ/min . It appears likely that the greatest uncertainty in the snoot flow rates is due to uncertainties in the calibration of the flow meter rather than in the orifices themselves.

A Variations in A are probably negligible.

E This factor is included in (1) and (2) for completeness. It will not be discussed in this section since it is properly a matter of sampler design and use rather than chemistry. In this section E is assumed to be 1.

VII DATA REDUCTION

The data reduction process is the final step in a munition evaluation, and conclusions concerning the munition are based directly on the results. In this section an outline of the techniques employed in FED are briefly presented. A number of field tests have been reviewed and in some cases analyzed by different techniques. A discussion of these studies is presented. Accuracy of results, improvements possible in the reduction process, and the derivation of additional results from existing data are also considered.

a) Area Dosage and Efficiency

One of the results of a field test is a graph of contours of constant dosage or numerical values of area for which the dosage is greater than or equal to a specific dosage level. The results are obtained by first plotting the values of dosage received from chemical analysis on a map of the horizontal grid. The data is then modified in that dosages which appear to be out of place or are missing are altered to fit a normalized model of the expected distribution (from experience). Two methods are employed in order to determine area dosage values. In the first of these, the planimetric method, contour lines are drawn on the map, and the area enclosed by each contour line is measured. The areas are then multiplied by the scale factor of the map and plotted.

In the second method, the point count, the dosage at each point on the map is assumed to be representative of that for the area defined by the half-way distances from that point to the neighboring points in all four directions. The area dosage is then determined by recording all of the points with dosage greater than or equal to the dosage to be plotted. The areas are then summed and the sum is plotted. The sum represents the area for which the dosage is equal to or greater than a specified level.

The second important analysis performed is that in which the efficiency and total return of a munition is obtained. In these computations the vertical grid plays a central role. The first step in the process is the plotting of dosages on a map of the vertical grid. As in the area dosage case, values may be changed to fit an expected distribution. Both point count and

planimetric techniques are employed in the analysis. In the point count method, the sum of dosages ($\frac{\text{mg-min}}{3}$) at each height is recorded. This sum is then multiplied by a factor which changes the units of the result to ($\frac{\text{g-hr}}{\text{m}^2 \text{ mi}}$) and corrects for the curvature of the arc. This product is multiplied by the average wind speed (mph) at that height and the resulting dosage in g/m^2 is recorded. Each of these numbers is then multiplied by an area (m^2), the product of the half-way distances to adjacent samplers. The sum of the products at each height is then the total number of grams of agent that passed through the grid. The planimetric method is similar to that described for area dosage.

Wind speed for each time interval is read from continuous recordings made at two points on the grid at several heights. Usually, the average of the two values at each height is plotted on a graph, and the wind speeds used in the above calculation are read from the graph. Occasionally, only values from one position are used.

In order to estimate the accuracy of the data reduction methods, the raw data and computed results were obtained from FED and analyzed at CAL. The basic difference in approach adopted by CAL from that normally employed was that all the data points were employed -- that is, no pre-analysis smoothing of the data was allowed. A comparison of the results obtained under this restriction for Field Test 1679 is presented in Table 2 and Figure 2. Densities rather than dosages are reported because sampling pan data was employed.

It can be seen that the CAL and FED results were in close agreement at the higher density levels for the planimetric method but deviated sharply for the low density values. This deviation was to be expected because considerable data were deleted in the FED analysis whereas no smoothing was employed at CAL except where samples were missing. There is considerable difference between the point count method and either of the others at the low density levels, whereas the higher density levels are in close agreement. This deviation is due to the method of assignment of areas for samplers in regions of low density, particularly in the outer grid and particularly so in the case of "hot spot" reading in these large areas. It is to be noted that good agreement between the methods was established in the mid density levels where the measurements are considered to be most exact.

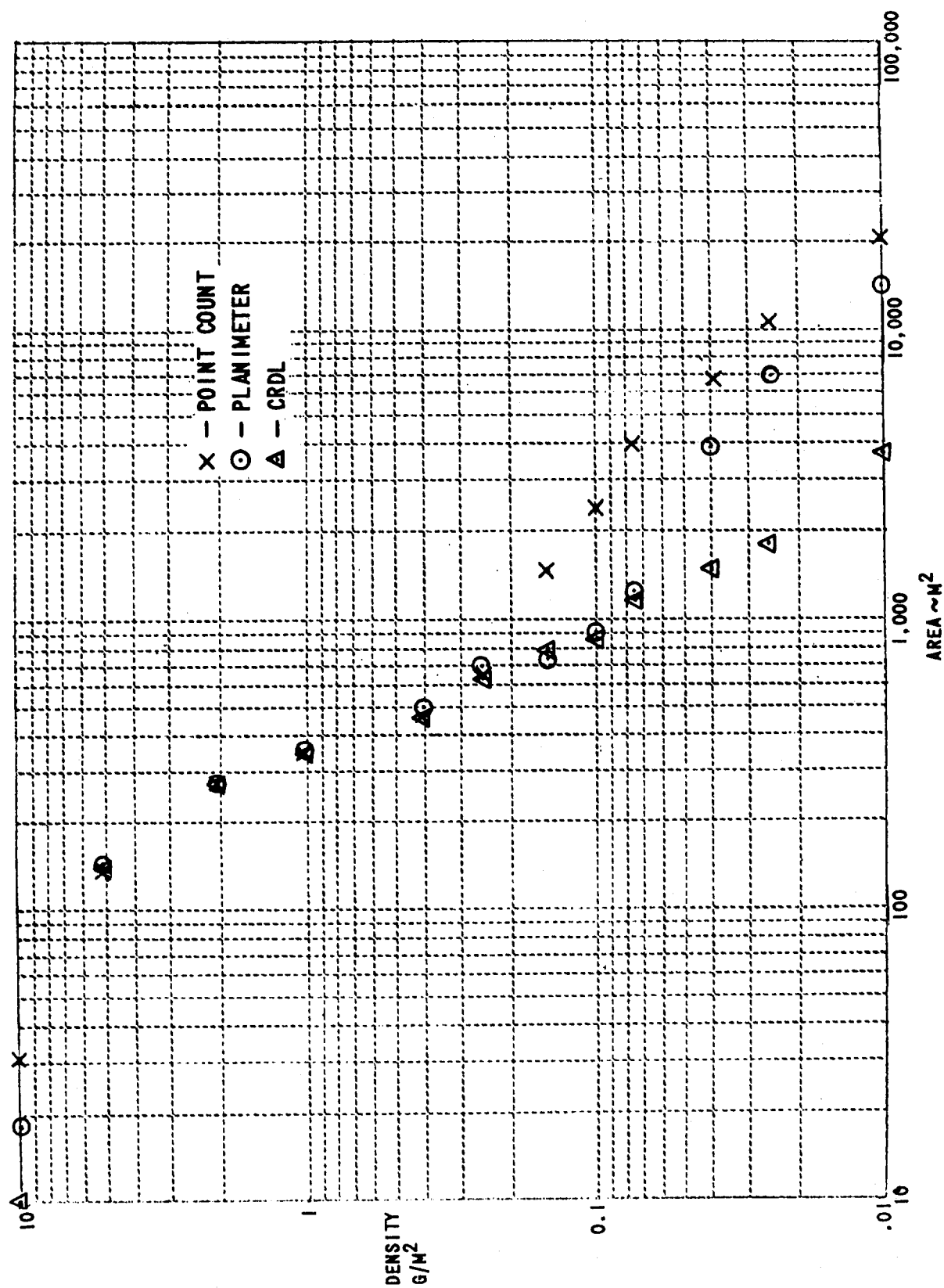


Figure 2 AREA VS DENSITY, FIELD TEST 1679

TABLE 2

Density gm/m^2	Point Count m^2	Planimeter m^2	CRDL m^2
10.0	30	18	10
5.0	135	139	142
2.0	264	264	261
1.0	345	350	347
.40	467	498	462
.25	641	693	635
.15	1480	736	780
.10	2370	887	871
.075	3980	1220	1164
.040	6650	3880	1498
.025	10750	6880	1814
.010	20900	14350	3699
.005	28500	22650	4020

To check the agreement between the point count and planimetric methods, the inner grid of Field Test 1421, 0-30 minute interval, was contoured by three operators and the results compared with those obtained by the point count method. The average and standard deviation of the three areas for ten dosages were calculated. The average standard deviation for all dosages was 3.7 square yards. The average area for each dosage ranged from 506 square yards to 8.6 square yards, but the standard deviation was not strongly dependent on dosage or area. The standard deviation was below 5 percent until the area was less than 40 square yards (dosage greater than $400 \frac{\text{mg-min}}{\text{m}^3}$). The average difference between planimetric and point count areas was 1.2 square yards, the planimetry values being higher; the standard deviation of the difference was 5.0 square yards.

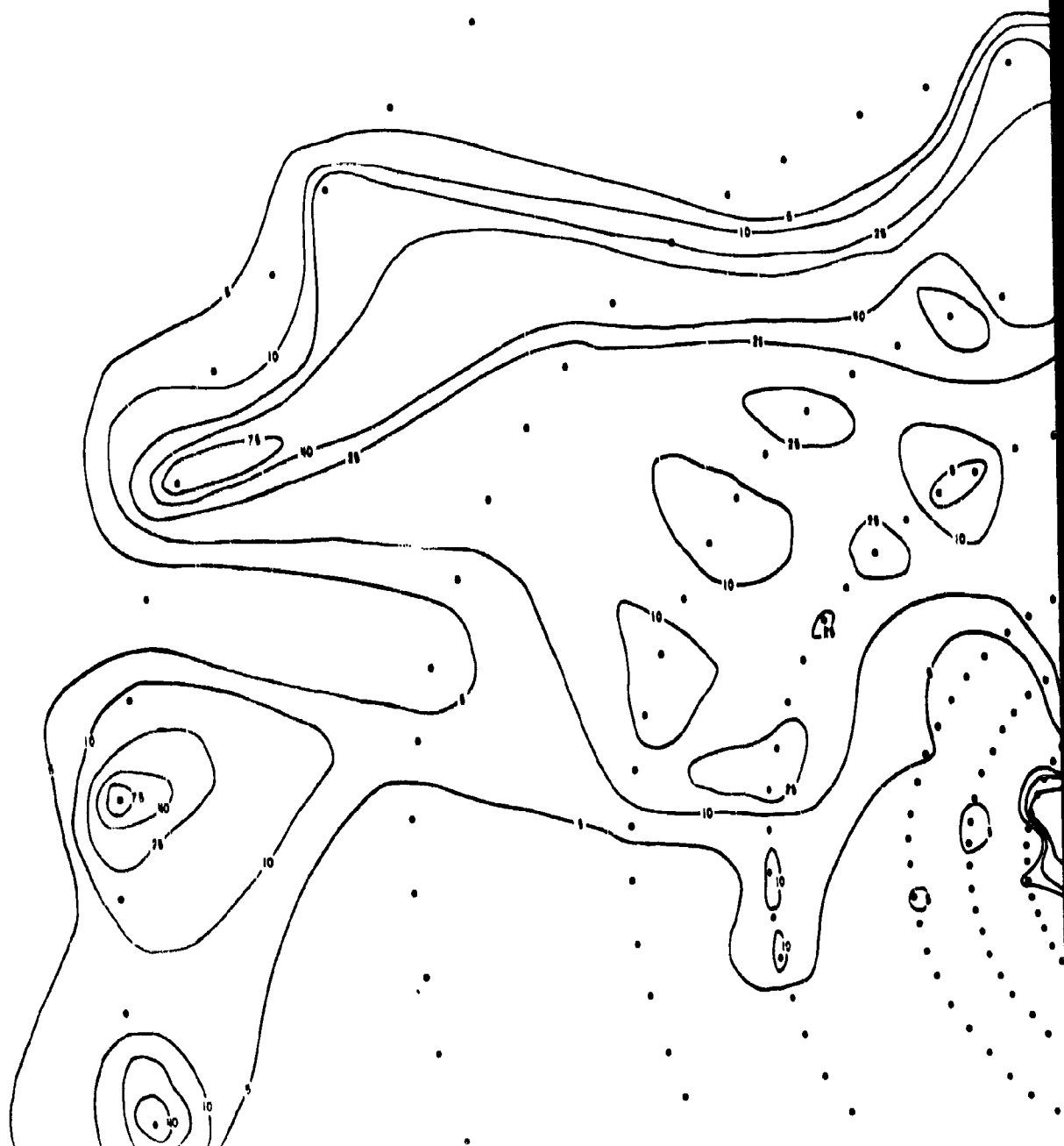
b) Mass Balance

In order to obtain a further check on the three techniques used to obtain the A-D curve for Field Test 1679, a mass balance was computed. The total number of grams of agent that fell on the test grid was calculated for the three curves shown in Figure 2. The total number of grams was calculated by multiplying the area associated with each density range by the lowest density in that range, thus obtaining a minimum value. The totals were: 1943 gm for the point count method, 1575 gm for the planimetric method, and 1268 gm for FED method. The amount of agent used was 1683 gm.

The total amount of agent that fell outside the 30-yard arc was also calculated and compared with the amount calculated to have passed through the vertical grid at the 30-yard arc. Beyond the 30-yard arc, the totals were: point count, 650 gm; planimetry, 76 gm; FED, 74 gm. Ninety gm were calculated to have passed the 30-yard arc.

Large deviations from the amount of agent actually disseminated are noted above for both the FED and CAL point count method. CAL's technique is to include all dosage readings as given by the chemical analysis. The area assigned to each sampler position is used to obtain the A-D curve. As stated above, it is assumed (in any point count method) that the dosage reading is constant over the assigned area. For Field Test 1679, a quick examination of Figure 3 reveals the "intense hot spots" of dosages received in the far arcs. These singular points cause the large difference in mass balance. Notice in Table 2 that all three methods of getting A-D data agree quite closely until the small density of 0.15 gm/m^2 is reached by the point count technique. From that point on, the outer grid readings have the largest effect. In the point count method, an isolated reading is the average assigned to an area which on multiplication of these factors give an area dosage volume. Possibly a better estimate would be obtained with a pyramidal rather than with the rectangular form employed. The difference in volumes is one-third. If one assumes a pyramidal type distribution and takes one-third of the area difference for dosage levels less than or equal to 0.15 (Table 2), a new, minimum, total, mass fall-out of approximately 1450 grams is received for Field Test 1679. This is a step in

1



2

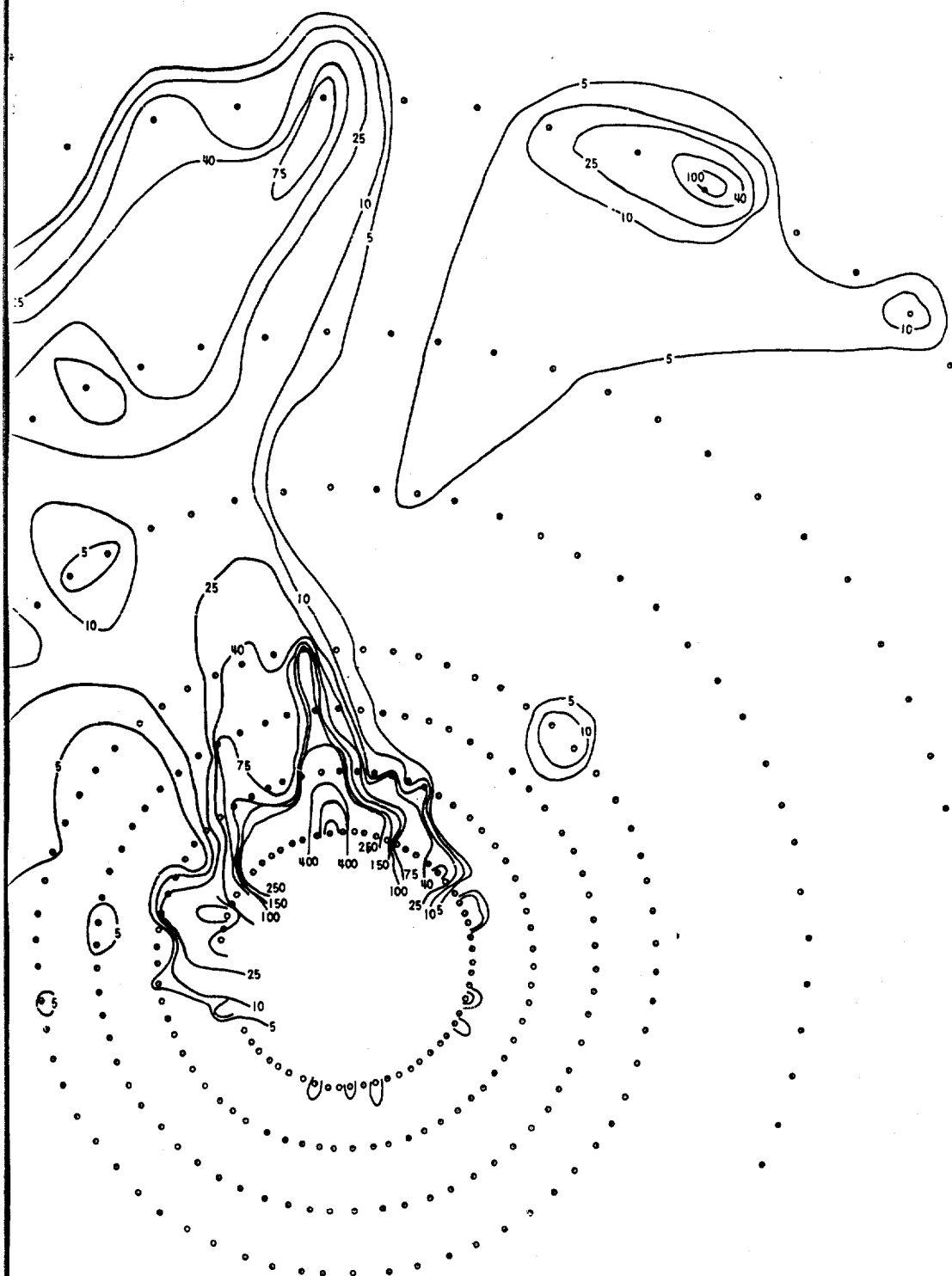


Figure 3 DENSITY CONTOURS FIELD TEST 1679

the right direction and does include the actual mass of 1683 grams. Obviously, the point count method, with the assumption of average dosage, will not give the right A-D curve. The mass fall-out will be too large.

The difference between the FED and CAL methods of point counting results from the inclusion of all dosage readings. One should include all data points but change the distribution. Further work on this will improve the point count technique (desirable from the standpoint of automatic data reduction).

The reason for good agreement of mass balance for CAL's planimeter method is the inclusion of all dosage readings, but as stated above the persons drawing the contour map (see Figure 3) had a tendency to pyramid (or peak) the distribution at isolated points. Therefore, the mass recovery of 1575 grams lies below the CAL point count total of 1943 grams but above the the FED point count of 1268 grams.

The above arguments hold for the mass balance calculations beyond the 30-yard arc (vertical grid position). Examination of the number of grams recovered for the FED method and CAL's planimetry method indicates a further discrepancy which tends to contradict the above "pyramid" argument, namely that the percent difference in mass balance between the FED and CAL methods for the material beyond the 30-yard arc is one-ninth the percent difference in mass balance for the entire grid. Thus, we obtain

$$\frac{76-74}{74} = \left(\frac{1}{9}\right) \frac{1575-1268}{1268}$$

Unfortunately, this contradicts the Laboratory's suggestion to include all sample points because the missing points are in the outer grid, so one would expect the above percent differences to be oppositely related. Further analysis is required to resolve this discrepancy.

The CAL planimetry method applied to the area beyond the 30-yard arc yields 76 grams, which figure differs by approximately 15 percent from the "true" mass of 90 grams obtained from the vertical grid calculations. But the same method yields 1575 grams for the entire grid which differs by only 6.5 percent from the 1683 grams of agent dissemination. If this method is correct,

indications are that the "true" mass of 90 grams is in error. To explain this, one has to examine both the types of samplers used and the subsequent chemical analysis to determine the accuracy of the readings. One explanation of the above difference (15% versus 6%) is that for this test BIS was used. The entire grid mass balance is obtained from sample pan data, the vertical grid from "snoot" data. Therefore, a determination of "snoot" accuracy is indicated.

All of the analysis at CAL (and FED) has been performed on a copy of FED's scale map of the vertical grid area on Carroll's Island (see Figure 3). It was discovered that on the plotting paper, the outer two circles of samplers (H and I) had a diameter 1 inch (13.3 yards) too small. This is an error of about 10 percent in the H circle and about 7 percent in the I circle, or 20 percent and 14 percent in the areas associated with these circles. There was also an average error of about 15 percent in the distance between points on an arc. Note that the area is smaller, making the total dosages less. Applying this error to FED's planimetry method should increase the mass recovery, thereby decreasing the error. This difference has not been computed.

c) Vertical Grid Error

A study was performed to determine the effect of errors in wind speeds and dosages on the value of total amount of agent calculated to have passed through the vertical grid. The example given is taken from the report of Field Test 1421. The following is a summary of the derivation of variance in the computed value of total agent through the vertical grid.

The total amount of agent which passes through the vertical grid is calculated according to the formula:

$$T = \sum_{h=1}^g K W_h A_h \sum_{i=1}^N D_{hi}$$

Where W_h = the wind speed at height h

- $D_h = \sum_{i=1}^N D_{hi}$ is the sum of the dosages at height h
 A_h = an area assigned to the height h , depending on the grid spacing
 K = a constant to convert units
 N = the number of non-zero dosages at height

If the standard deviations (square root of the variance) of the W_h and D_{hi} are known to be $S(W_h)$ and $S(D_{hi})$, and the standard deviations of A_h and K are assumed to be negligible, then $S(T)$ is given by:

$$S(T) = \sqrt{\sum_{h=1}^q S^2 W_h D_h A_h K}$$

where

$$\frac{S(W_h D_h A_h K)}{W_h D_h A_h K} = \sqrt{\frac{S^2(W_h)}{W_h^2} + \frac{S^2(D_h)}{D_h^2}}$$

and

$$S(D_h) = \sqrt{\sum_{i=1}^N S^2(D_{hi})}$$

If $S(W_h)$ is assumed to be 5 percent of the measured value of the wind speed, and $S(D_{hi})$ 10 percent of the given dosage, $S(T)$ is as follows:

$$\begin{aligned}
 S^2(D_h) &= \sum_{i=1}^N .01(D_{hi})^2 \\
 \left(\frac{S(W_h D_h A_h K)}{W_h D_h A_h K} \right)^2 &= .0025 + .01 \frac{\sum_{i=1}^N (D_{hi})^2}{\left(\frac{\sum_{i=1}^N D_{hi}}{N} \right)^2}
 \end{aligned}$$

$$S_{(T)}^2 = \sum_{h=1}^q W_h^2 D_h^2 A_h^2 K^2 \left[.0025 + \frac{.01 \sum_{i=1}^N D_{hi}^2}{\left(\sum_{i=1}^N D_{hi} \right)} \right]$$

The first term in the sum is the contribution from the $S_{(W_h)}$, and the second term is the contribution from $S_{D_{hi}}$. If the D_{hi} are assumed identical for each h , the second term reduces to $\frac{.01}{N}$ where N is typically between 1 and 10; thus, the contributions are of the same order of magnitude.

Using the data from Field Test 1421, 0 to 30-minute time interval, is calculated to be 64.0 and $S_{(T)}$ to be 2.48 or about 4 percent of the total. Note that this error of 4 percent is less than the error in the measured wind or dosage. This error reduction is primarily due to the summing process. For example, if the error in each reading of a variable is equally likely to be high or low, and several of these measured variables are summed, it is likely that the sum will approach the true sum as the number of measurements increases.

Calculations for the above example are as follows:

Dosages		(mg min/m ³)		
h =		1	2	3
		(0.2M)	(0.5M)	(1.0M)
i	= 1	4	11	6
	2	10	27	13
	3	15	32	16
	4	42	29	14
	5	35	19	9
	6	26	12	
	7	17	3	
	8	4		
$\sum D_h$	=	153	133	58
$\sum D_h^2$	=	4311	3229	738
W_h	=	7.2 mi/hr	9.0 mi/hr	10.3 mi/hr
A_h	=	0.70 yd/m	.80 yd/m	1.50 yd/m

$$K = 24.4$$

$$T = 18.8 \text{ gm} + 23.4 \text{ gm} + 21.8 \text{ gm} = 64.0 \text{ gm of agent}$$

$$\begin{aligned} S^2_{(T)} &= 18.8^2 \left[.0025 + \frac{43.11}{(153)^2} \right] + 23.4^2 \left[.0025 + \frac{32.29}{(133)^2} \right] \\ &\quad + 21.8^2 \left[.0025 + \frac{7.38}{(58)^2} \right] = 6.13 \end{aligned}$$

$$S_{(T)} = 2.48 \text{ gm}$$

d) Variance of Wind Speed

Values of wind speed were read from continuous recordings at 3-second intervals from burst to 2 minutes, and at 1-minute intervals from 2 minutes to 30 minutes. The average (\bar{V}), and standard deviations (S), of these values and the averages obtained by FED are recorded in Table 3 for intervals of 0-15 seconds, 0-30 seconds, 30-120 seconds, and 2 to 30 minutes. The averages recorded by FED were obtained by placing a stretched string on the recording and estimating the string position at which the areas on both sides were equal. There were no averages recorded by FED for the 0-15 second interval.

The data is from Field Test 1421, position 33.5. The average of the differences over all intervals except the 0 to 15-second interval, is 0.003 mph. The standard deviation of the differences is 0.11 mph. These data will be used to estimate the variance in the total dosage computations as given in the previous subsection c.

e) Improving Data Reduction Process

1. As mentioned earlier, the plotting paper used for contouring is not accurate. This inaccuracy must be corrected.

TABLE 3

Average and Variance of Wind Speed (mph)

	0-15 sec			0-30 sec			30-120 sec			2 min - 30 min		
Height	\bar{V}	S	FED	\bar{V}	S	FED	\bar{V}	S	FED	\bar{V}	S	
0.3 M	7.70	0.84	7.2	7.24	0.53	8.2	8.23	0.73	7.4	7.63	0.95	
1.0	10.27	0.51	9.8	9.72	0.80	11.0	11.14	1.14	10.0	9.92	0.76	
2.0	11.30	0.15	10.8	10.78	0.62	12.2	12.03	1.31	10.8	10.66	1.09	
4.0	13.30	0.42	12.6	12.72	0.75	13.5	13.66	1.13	12.8	12.63	1.26	
8.0	14.12	0.86	14.3	14.34	0.74	15.5	15.44	1.13	14.7	14.61	1.02	

2. The standard curves generated in the chemical laboratory should be processed by the data reduction group. If possible, data reduction should be handled automatically with the digital computer.

3. Chemical analysis should be performed automatically for several reasons, such as: 1. ease of operation, 2. elimination of human error, 3. allowance for backtracking if a mistake is found, 4. allowance for a more exact estimate of error in the chemical analysis.

4. Map generation should be done automatically if the need for the planimeter method persists or the desire to observe the resulting distribution of agent dissemination is a required result of field testing. A "machine" to generate contour maps may exist in the weather bureau or geodetic map agency. Of course, for the larger items (bombs) the inner grid data may need "filling-in" because of pans or other samplers destroyed by the blast.

5. The point counting technique lends itself quite nicely to automation; unfortunately, as shown above, it is quite sensitive to distribution. Unless this barrier is overcome, the point count method may be useless.

6. The only way to save the point count technique (and curve fitting) is to derive a distribution for widely scattered dosages. In other words, the point count cannot be applied without knowledge of a distribution of points; i. e., to process any particular point, one must have knowledge of the points surrounding it. Obviously, this is done in the planimeter method or by an eyeball "smoothing" technique of FED (e. g., leaving out points, interchanging points, etc.).

7. The discussion of distribution leads to the analysis performed at CAL for the gaussian model of diffusion. The fit of a gaussian (normal) curve to the cross-wind dosages appears to be quite accurate, but the resulting A-D curves or mass balance are as far from the true value as the point count technique (at least for Field Test 1679). Again, the assumed smoothed distribution effected the results. For example, on Field Test 1679, the total dosage was 2050 grams compared to the actual dissemination weight of 1623 grams and the dosage beyond the 30-yard arc was 610 grams compared to vertical grid total dosage of 90 grams. These dosage estimates are larger than those received by the point count technique.

The above dosage values quoted for Field Test 1679 were obtained from the plotting technique. The values of σ were read from the graphs on probability paper. Because the integral of the normalized distribution is 1, the maximum density on each arc can be found by multiplying the sum of the densities by the factor $1/\sqrt{2\pi\sigma^2}$

The results are shown below:

TABLE 4

Circle	$\sum_{ALL} D(u)$	σ in points	σ in yards	D max	Position of max
B	6414	6.0	12.0	428	36.0
C	1671	2.6	7.8	256	36.5
D	468	2.0	7.8	93	35.8
E	415	3.3	16.2	50	37.5
F	318	5.3	38.8	24	28.5
G	351	4.8	47.0	29	32.5
H	566	5.5	80.7	41	37.0
I	373	3.2	62.7	46	23.9

Regardless of its inaccurate estimates for scattered distribution, the model fitting does lend itself to automation. To use automation with this method, CAL personnel derived a technique for mathematically obtaining the A-D curve and total dosages. The following approach is one method lending itself to automation:

If $D_{(n)}$ is the dosage at arc position n , let the cumulative fractional dosage $U_{(n)}$ be given by

$$U_{(n)} = \frac{\sum_{i=0}^n D(i)}{\sum_{ALL i} D(i)}$$

where i is 0 at a point opposite the greatest dosages. Then define $x_{(n)}$ by the following:

$$U_{(n)} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x_{(n)}} -x^2/2 dx$$

$x_{(n)}$ is then a linear function of n , and a least squares fit can be made in the usual manner.

The standard deviation σ , in arc positions, can be read from the $x_{(n)}$ line. It is also possible to get a smoothed dosage distribution by taking the $x_{(n)}$ from the line and proceeding backwards through the above steps. ($\sum_{ALL i} D(i)$ must be calculated from the original data.) This provides the necessary smoothed, or model-fitted, distribution.

f) Additional Uses of Existing Data

Only a few items of interest are obtained from the present field test data. CAL hopes to extend the following list as the study continues:

1. Describe the accuracy of the results given to the sponsor. This description can be in the form of the standard deviation of certain results or perhaps the "confidence" in certain answers.
2. Describe the distribution obtained, e.g. widely scattered.
3. Provide the actual A-D curve using all of the dosage data received from chemical analysis. Derive a smoothed model that satisfies the actual A-D curve. This model may be of the gaussian shape or of the fallout shape for aerosol proposed by Davidson (Ref. 6).

4. Provide a summary of the test to be used as a catalog entry for future use of model fitting; provide information variation of results with certain meteorological conditions; and so on.

g) Reducing the Number of Samplers

The most likely area for reducing the number of samplers is on the inner grid. The significance of having an accurate estimate of the total dosage or distribution of agent on the inner grid is questionable for two reasons:

1. The dosage is usually an overkill and not a significant result of the test (more interest should be given to the area covered for minimum "kill").

2. For flashing type munitions as with VX, this data cannot be used for a mass balance. Mass balance is determined by the vertical grid and outer grid. The inner grid dosage provides an estimate of the amount of agent that flashed, but this could probably be a 10-percent estimate without degrading the effectiveness of a comparative test. (Vertical and outer grid data are assumed to be accurate, to say 5 percent.)

In order to demonstrate the effect of reducing the number of samplers, the inner grid data of Field Test 1679 was used. The dosage readings recorded by FED were used to get the A-D curve using the point count technique. Then, a new array of samplers was selected so that the area covered by each sampler was double that used in the first A-D curve estimate. That is, half the samplers were used (172 versus 86) for a second estimate of the A-D curve (and dosage if needed). The two A-D curves agreed to within 10 percent of each other. More studies of this type can be performed in the future.

VIII TEST TIME REDUCTION

One of the major problems facing FED is the overload of their test facilities due to the large amount of testing scheduled. For the present year there are approximately 36 complete programs on the schedule with each program requiring from a few to very many (~ 30) tests. These programs involve the use of all the FED facilities, including the Explosion Chamber, Wind Tunnel, Field Bunker, and Grids. It is estimated that if each program were carried through to completion the number of individual test runs would approach a thousand.

Because of the large test backlog a major problem is introduced when priority of testing is introduced. The emphasis may shift from the testing of one weapon or munition to another, leaving programs already started to be completed at some future date. Loss of coherence or correlation between the individual tests of a complete program may follow. It is readily appreciated, however, that emphasis is beyond the control of FED and the only way to remove its effect is to develop test programs which can be conducted in a time frame short compared to the frequency of that input.

The problem could be solved in theory by developing new test methods which would remove the large amounts of time presently required. For example, the development of a device that would produce a real time readout of the agent concentration thereby excluding the lengthy processes of storage, sample transportation, and chemical analysis, would be a most valuable introduction. In fact, such equipment would also remove the problem of gross inaccuracy introduced by sampler handling. It can be expected that considerable FED effort will be expended in this area and that systems of the future will be more timely.

Consideration must be given, however, to the existing systems because these systems will be in use for some time and because the development of equipment of real time character cannot be assured at this time. Therefore, it is planned that during the second half of this program emphasis will be placed on the time procedures of the existing system. While no definite work schedule has been prepared, such a schedule would likely include the following areas:

1. Revised method of test plan design
2. Minimum delay test analysis particularly for wind tunnel and explosion chamber tests where the test rate can be quite high
3. Expansion of automatic chemical analysis techniques
4. Modification of present field operation
5. Development of new analysis procedures
6. A chemical analysis laboratory for the wind tunnel

It should be noted that some consideration to timeliness is also given in Section IX. It has been found that it is not possible in all cases to separate accuracy from timeliness particularly in areas where organization or structure is in question, and it can be expected that a truly successful solution to the time problem would lead to improvements in accuracy also.

IX PLANS

An outline of the effort to be continued or undertaken in each of the major areas has been included in Sections III, IV, V and VI. The results which will be most vigorously sought are the determination of the process accuracy and the areas which contribute most significantly to loss of accuracy. In addition to defining such areas, solutions to the problems will be sought. The subjects of test planning, test time reduction and instrumentation studies will be expanded.

Several subjects have been proposed for study which have not been previously considered and which are concerned primarily with the approach to testing found to exist in the Field Evaluation Division or with new concepts. These subjects, presented below, will also be developed in the following period.

a) Calibration

It would seem imperative that in tests of the magnitude of those carried out at FED, some systematic calibration procedures must be employed and that some method of calibrating each important phase of a test as well as the overall test be introduced. This single input would be of considerable value in maintaining a high level of confidence in the validity and accuracy of the data and in the development of a better understanding of the dissemination process by allowing more detailed correlation analyses to be carried out.

b) Test Authority

In order to introduce calibration techniques into FED testing some change in technical authority may be suggested. At present, such authority is distributed nearly uniformly among the four sections and all data is accepted on sight. Two possible solutions can be seen. In the first, a staff position would be created which would be filled by a person responsible for measurements, who would be responsible for all equipment or processing accuracy. In the second, the responsibility for accuracy would be placed on a senior engineer designated to be the "Test Director" who would hold this position for the entire program involving a single munition. In this latter case there would be a requirement for several "Test Directors" inasmuch as several programs are in process simultaneously.

c) Field Test Tracer

One proposal evolved thus far, which is presently considered to warrant considerable study, considers the use of a tracer material to be released in fixed amount and by a fixed device each time a test is performed. The basic aim would be to develop a complete description of the test in such a way that sampler data for active agent could be easily checked to allow a valid base for the comparison of the results of several tests. It would also allow a catalog of results of a common test to be rapidly developed. The requirements for such a system would include noninterference of materials, and the development of a simple, fast, accurate detection system for the tracer.

d) Phase Testing

One subject that needs to be considered is that dealing with the actual dispersal of material by the munition. In many cases, the downwind dosages are primarily a function of the meteorology and the amount of material disseminated. Unless particle size is involved, it may be possible to consider a test which can be conducted under controlled conditions which would be performed to determine the dissemination in the vicinity of the munition. After a description of this process over a range of parameters, the field test cloud could be simulated by alternate disseminating devices, removing much of the present clutter from the test. Also, the effects introduced by munition design variations might much more easily be observed in such a test than may be possible with full-scale grid tests.

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